



PLASMA SCIENCE AND FUSION CENTER

OVERVIEW

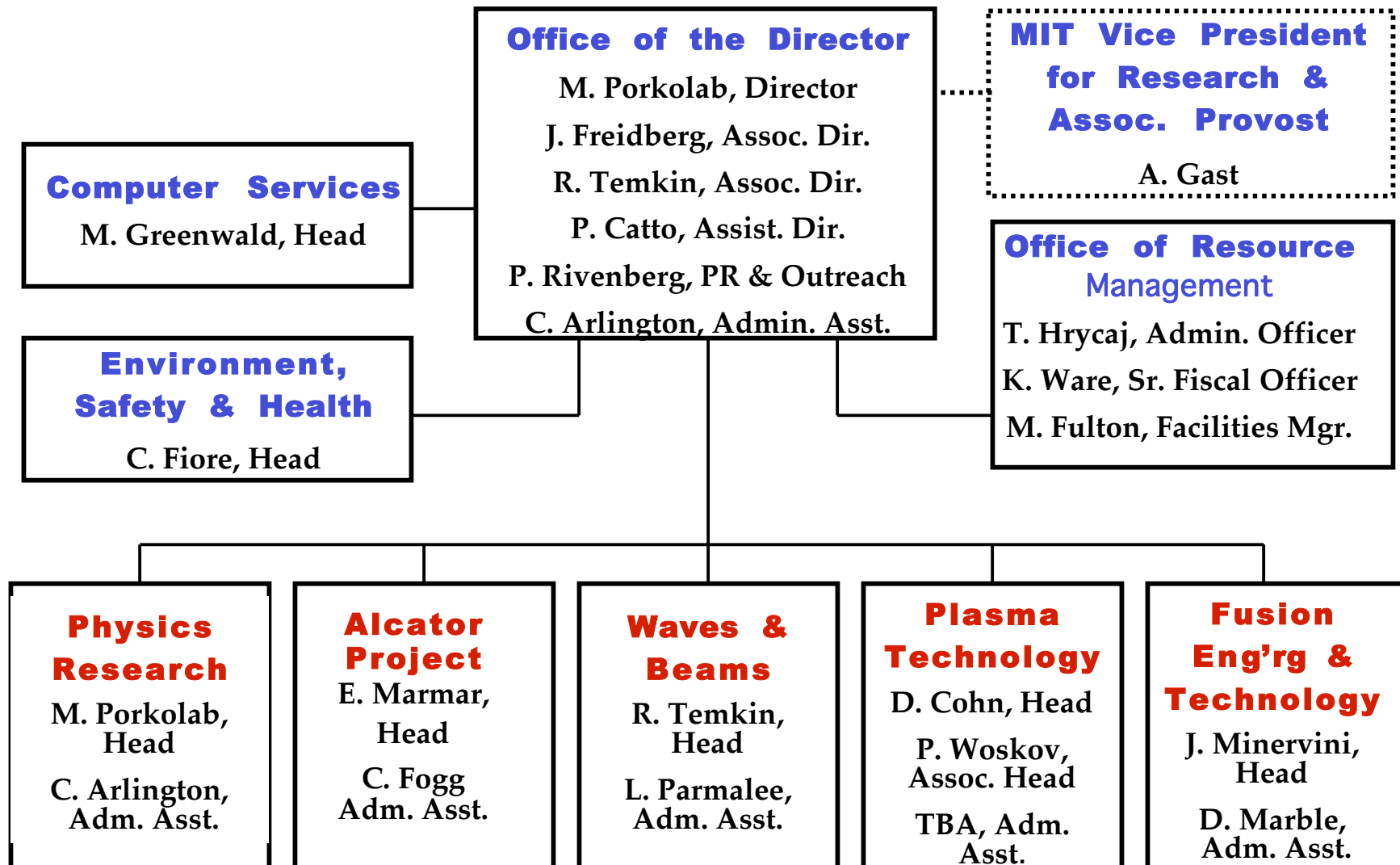
Miklos Porkolab

Director

**OFES Budget Planning Meeting
March 15-16, 2005
Gaithersburg, MD**



PSFC ORGANIZATION CHART





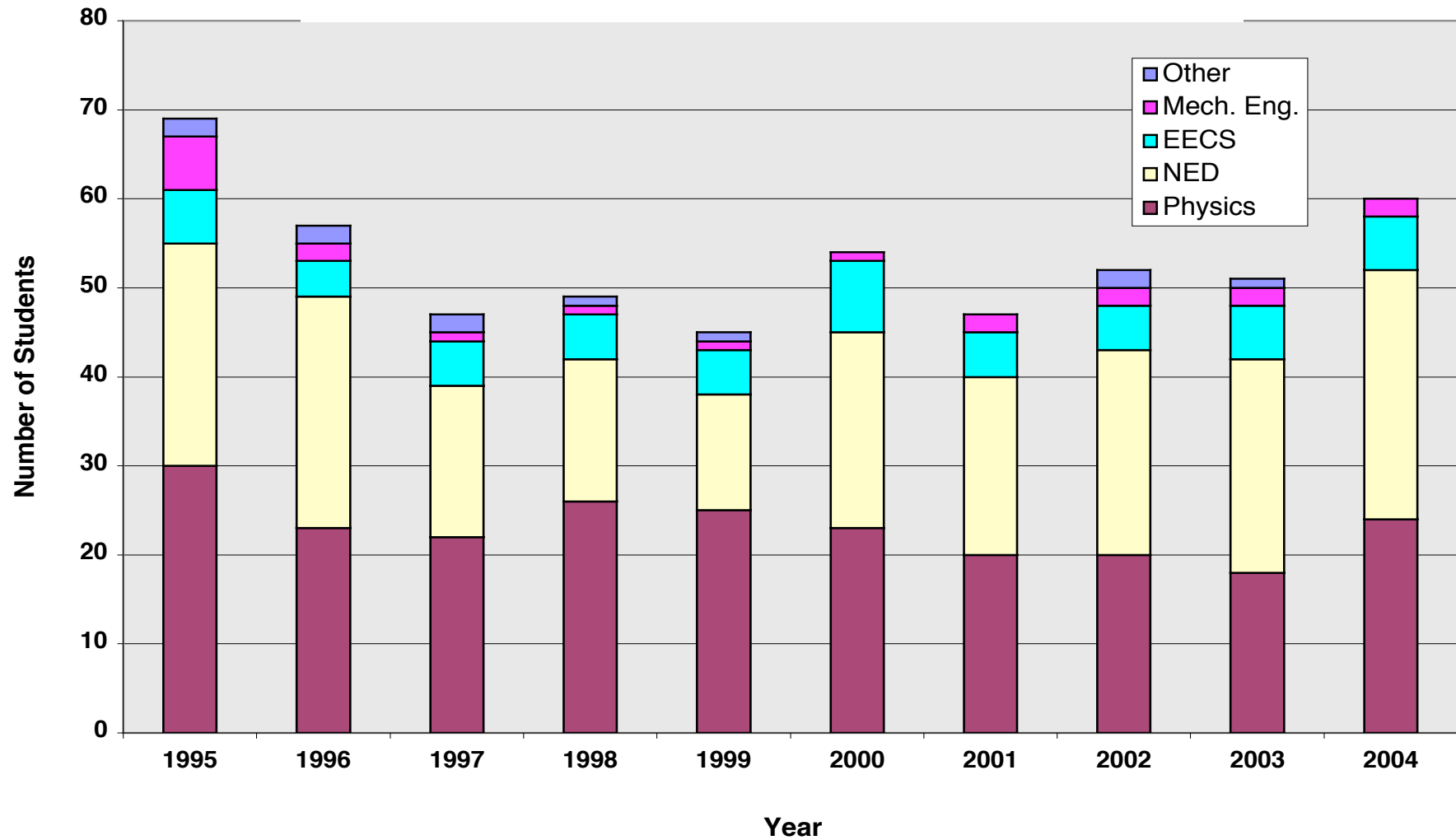
PSFC PERSONNEL

(3/15/05)

	<u>FY00</u>	<u>FY01</u>	<u>FY02</u>	<u>FY03</u>	<u>FY04</u>	<u>FY 05</u>
Undergraduate Students	6	5	9	17	15	16
Graduate Students	54	47	52	56	57	61
Faculty/Sr. Academic	18	16	18	18	18	18
Engineering/Scientific Research Staff	65	68	72	73	73	78
Administrative Staff	10	12	13	12	11	11
Support Staff	11	9	10	13	14	13
Technicians/Drafters	<u>28</u>	<u>30</u>	<u>30</u>	<u>31</u>	<u>31</u>	<u>30</u>
	192	187	204	220	219	227
Visiting Scientists & Staff Engineers	58	54	61	53	50	43
TOTAL	250	241	265	273	269	270

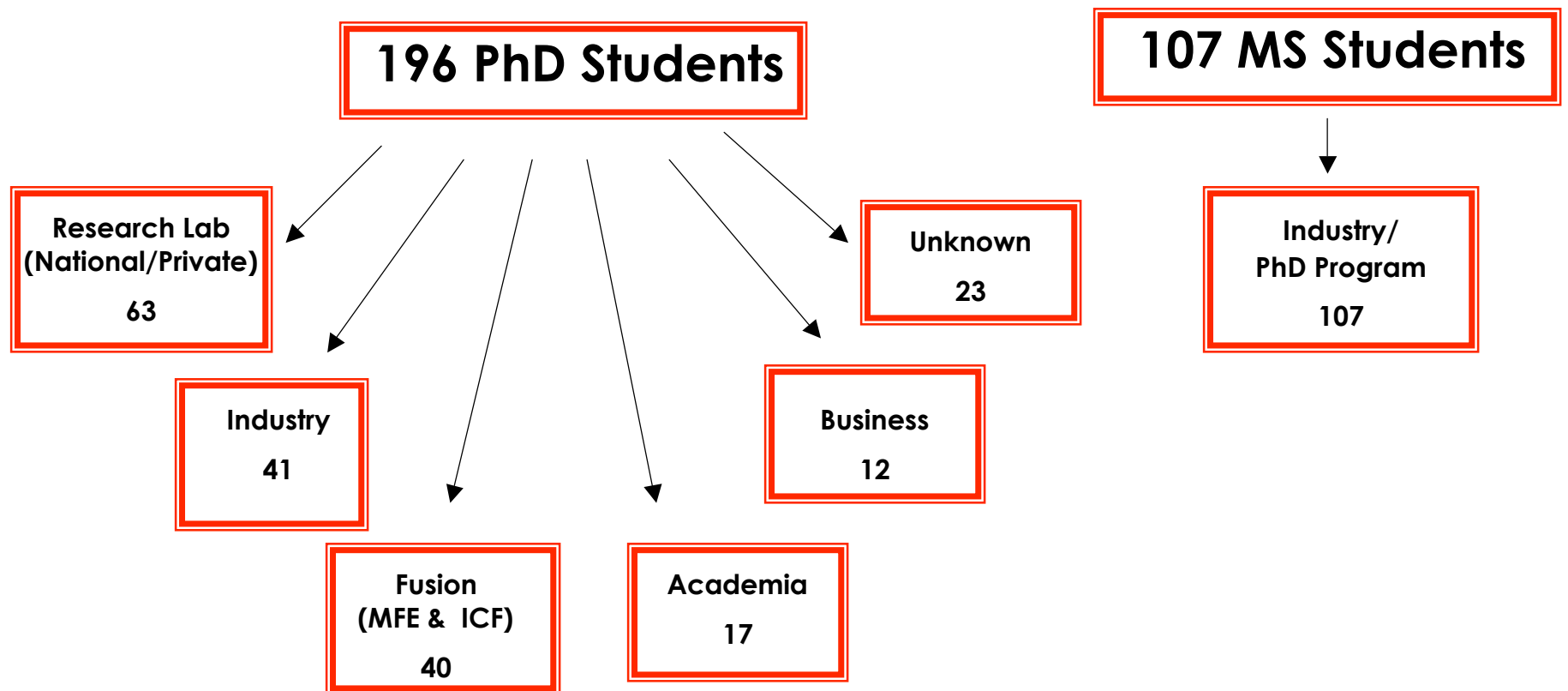


Total Number of PhD Students at the PSFC Per Year



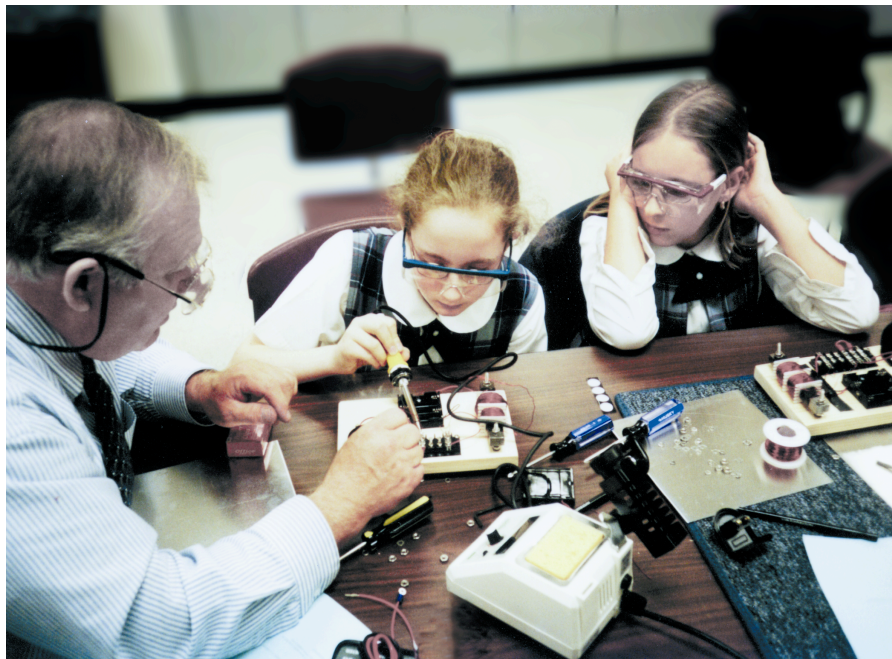


Employment Status of MIT PSFC PhD/MS Students Beyond Graduation (1980–2004)





Vigorous K-12 Outreach Program by PSFC Staff



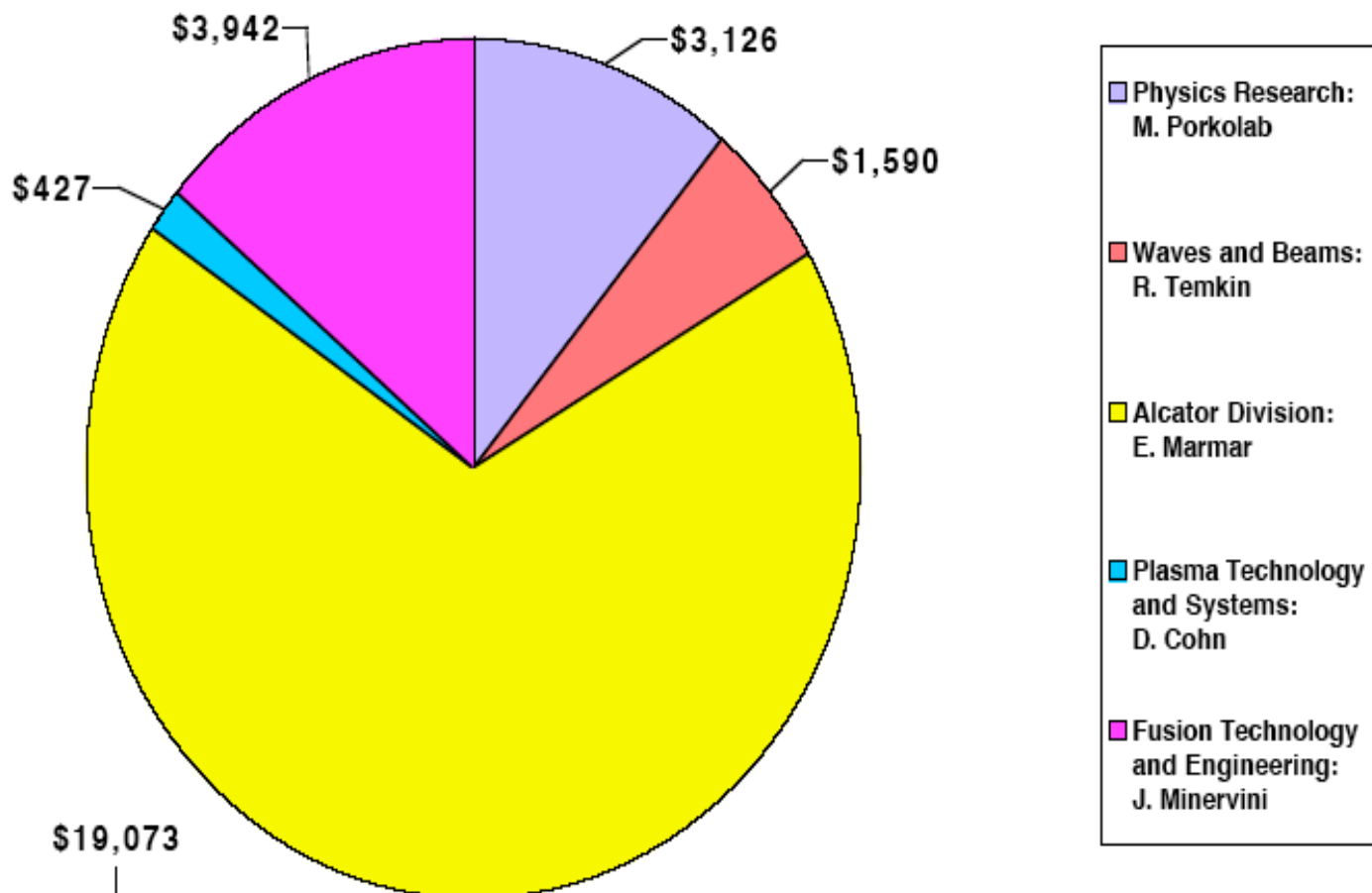
**Paul Thomas, aka Mr. Magnet
“in action”**

- The Mr. Magnet Program (Paul Thomas) reaches over **30,000** students per year.
- The Center provides over 35 tours of the Center per year, reaching over **900** K-12 students, teachers and general public.
- MIT PSFC supports growing APS-DPP education activities, and led these outreach efforts in 2004 in Savannah, GA.
- PSFC helps maintain and expand Coalition for Plasma Science educational activities, including website and publications.
- Plasma demonstration display exhibited at the Boston Museum of Science



PSFC Budget Chart by Divisions, OFES Funding

PSFC OFES FY06 FUNDS (in thousands): TOTAL \$28,158





PSFC BUDGET PROFILE BY DIVISIONS

PSFC DIVISION	FY04 Budget	Projected FY05 Budget	Projected FY06 Budget	Add-on FY06B Budget	Projected FY07 Budget	Add-on FY07B Budget
Physics Research: M. Porkolab	3,149	3,197	3,126	401	3,136	457
Waves and Beams: R. Temkin	885	1,158	1,590	16	1,590	16
Alcator Division: E. Marmor	19,727	19,518	19,073	6,824	19,897	6,365
Plasma Technology and Systems: D. Cohn	418	427	427	0	427	0
Fusion Technology and Engineering: J. Minervini	2,895	3,054	3,942	282	3,942	282
DOE OFES Total:	27,074	27,354	28,158	7,523	28,992	7,120

Budget projection does not account for significant increases needed for Fusion Technology Division in FY 06, 07 if ITER were to proceed to construction



ALCATOR C-MOD ADVANCED TOKAMAK - A National Facility

(See detailed presentation by Earl Marmor)

- Purely RF heated plasma regimes at ITER (burning plasma) relevant fields (5-8T), densities ($n_e \sim 1 - 5 \times 10^{20} \text{m}^{-3}$), and collisionalities with metallic PFCs
 - 8 MW ICRF operational for heating, CD and flow drive
- Advanced Tokamak (AT) Program:
 - Quasi-steady state configuration ($\tau \sim L/R$) at $B \sim 5\text{T}$ with high bootstrap current fraction and LHCD current profile control
 - 3MW of 4.6 GHz LHCD power has been installed and commissioning has commenced
- 29 graduate students doing Ph.D. theses on C-Mod
- Reduced funding and operation of 12 weeks in FY06 detrimental to providing physics database for ITER and PhD student training



PHYSICS RESEARCH DIVISION Experiments

A. Levitated Dipole Experiment (LDX) (Columbia-MIT Collab.)

Experimentation begun 8/04. Have achieved $\beta \sim 7\%$.

Additional funding for Fy 06 would increase run time and student RA

B. Driven Magnetic Reconnection Experiments on VTF

Newly funded by OFES in FY04; two PhD students on ORISE DOE fellowship make marginal project funding functional; need technician

Participating in OFES funded “Center for Multi-Scale Plasma Dynamics”

C. Advanced Diagnostics

(1) Phase Contrast Imaging (PCI) upgrade proceeding on DIII-D and C-Mod to look for short wavelength modes (ETG, TEM, IBW, ICW)

(2) Collective Thomson Scattering upgrade on TEXTOR, ASDEX-U:
(An MIT PSFC- RISO/Denmark collaboration)

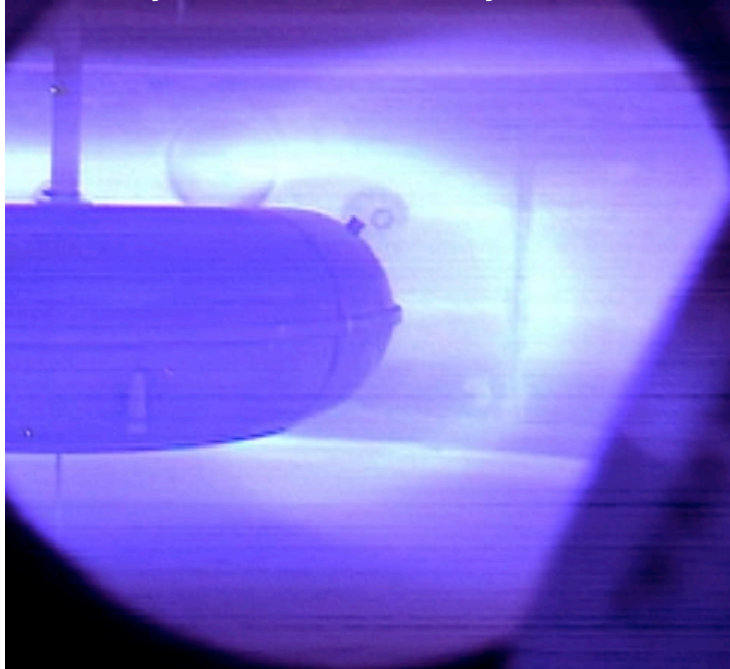
D. JET-MIT PSFC Collaboration on TAE modes

MIT-JET-CRPP collaboration-New antenna fab for JET by CRPP

F. HEDP

Participating in OFES Science Center with Univ. Rochester

LDX Physics Studies Underway Summer 2004!



A partnership of innovative plasma science and magnet technology

Completed fabrication and integrated testing of high-field superconducting magnets in FY04

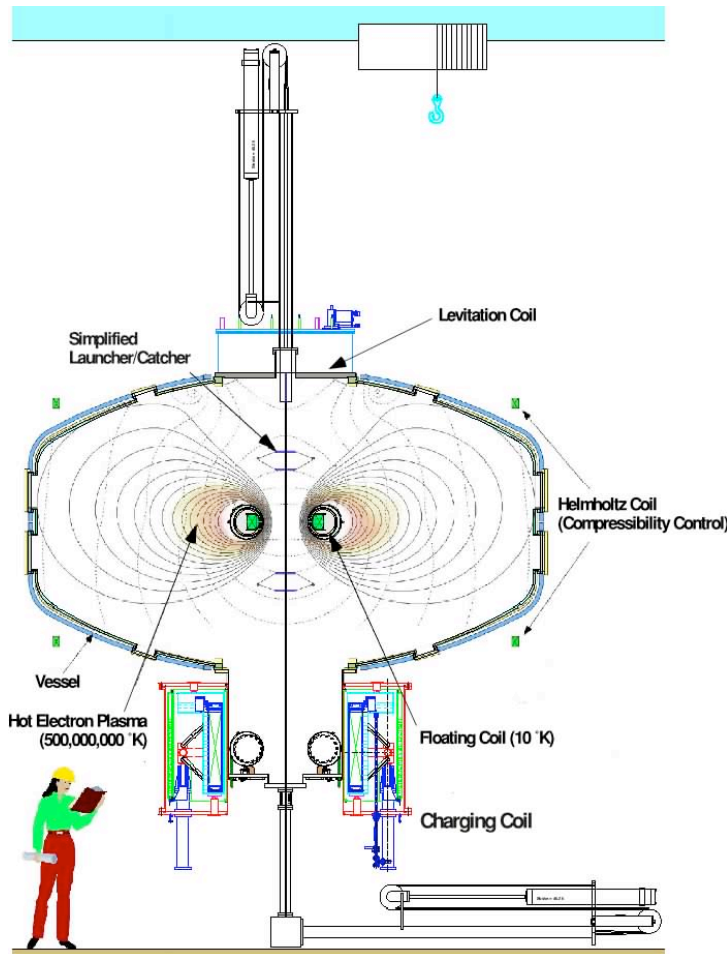
US Fusion Program's only ongoing experiment with superconducting magnets

Can fusion benefit from nature's way to confine high-beta plasma ?

FY04-05 Achievements

- **Phase 1: Plasma experiments with supported coil (now).**
 - ✓ **Quasi-steady state plasmas** created with more than 10 s multi-frequency ECRH (6 kW).
 - ✓ ECRH creates **central torus of energetic electrons** (10 ~ 30 keV) supported by a cooler plasma extending outward.
 - ✓ Equilibrium reconstruction using arrays of flux loops and magnetic coils show **high beta** ($> 7\%$) with peaked profile and marginal gradients, $\delta(PV) \sim 0$.
 - ✓ Interferometry and edge probe measurements consistent with **peaked density profile**, beneficial to dipole concept.
 - ✓ **External coils** modify plasma boundary, compressibility.
- **Phase 2: Plasma experiments with levitated coil on-track for Summer 2005.**

Can we produce well-confined, high-beta plasma with a levitated dipole and understand large-scale adiabatic convection that maintains energy confinement while allowing rapid removal of impurities and fusion products?



FY06 Campaign

- Continue basic physics explorations of high-beta, high-temperature plasma confined by levitated dipole magnet

Use magnetic, optical, x-ray, microwave, and probe diagnostics to study and understand equilibrium and dynamical processes within a high- β dipole plasma. Edge studies. Investigate convective flows. Continue studies of dipole particle and energy confinement.

- Install additional ECRH sources and expand operational parameters to higher density and β .

Test ability to control pressure profile with high power, multiple-frequency ECRH. Study higher-density thermalized plasmas.

FY07 Campaign ("Full Use Budget")

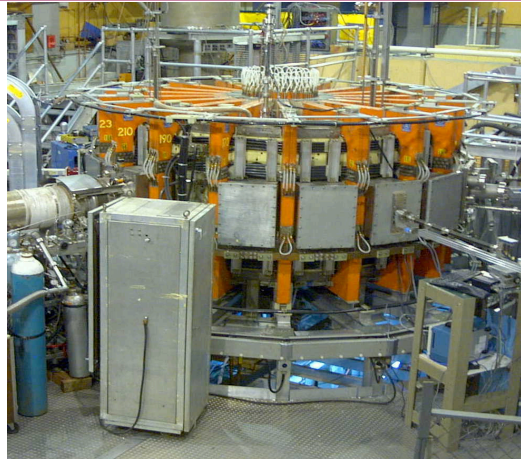
- Expanded diagnostics for detailed physics observations, and allow increased run time of LDX experimental facility.
- Investigate the unique capability of a dipole for high plasma beta, high energy confinement, and adiabatic convective flows.
- Answer questions to evaluate the potential for attractive dipole fusion with advanced (non D-T) fuels.
- Funding reduction (-10%):** would limit purchase of cryogenics needed to run superconducting magnets and eliminate support for a graduate student.



Reconnection Experiment in VTF in the Open Field Configuration

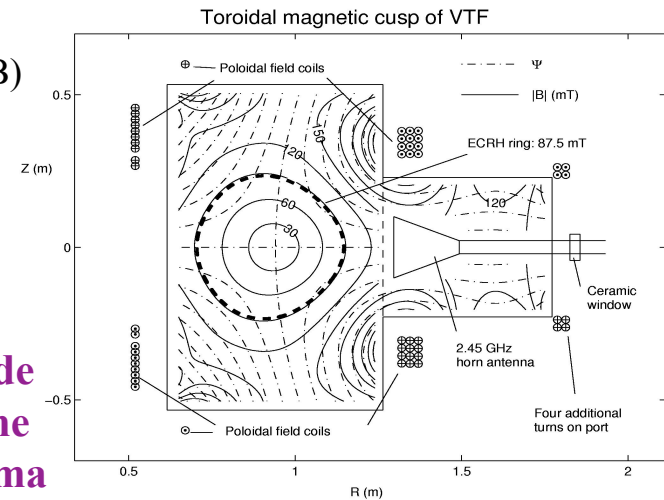
Provide Scientific Understanding of the WIND Satellite Data

(A)



(A) The Versatile Toroidal Facility (VTF)

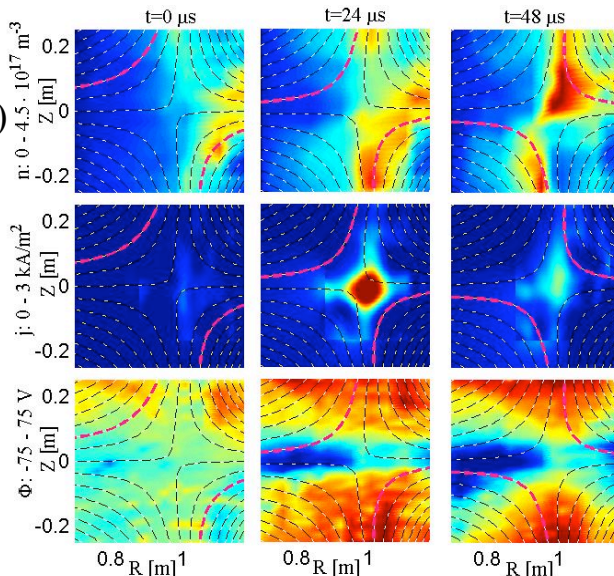
(B)



(B) Open magnetic field configuration

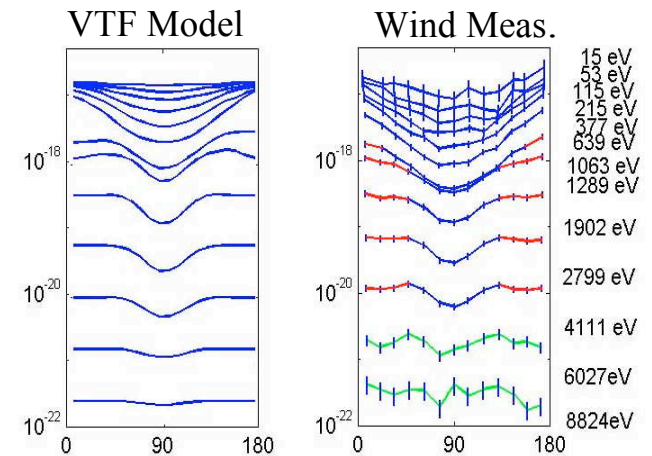
(C): Measurements provide detailed information on the time evolution of the plasma density, current and electrostatic potential

(C)



(D) **RIGHT:** Electron distribution measured by the WIND satellite during passage through the Earth's magnetotail at 60 R_{earth} . **LEFT:** The VTF orbit kinetic code reproduces the WIND data during magnetic reconnection.

(D)



J. Egedal et al., (2005) Phys. Rev. Lett. **94**, 025006

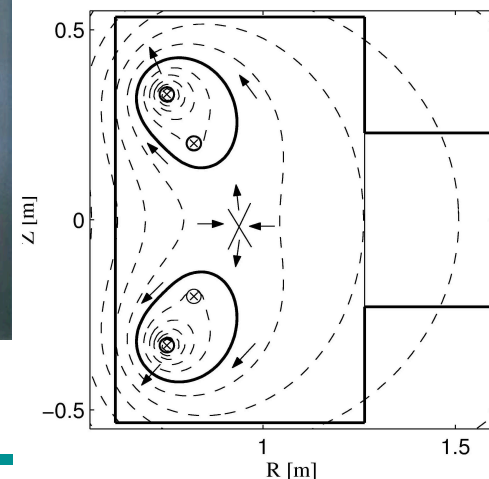
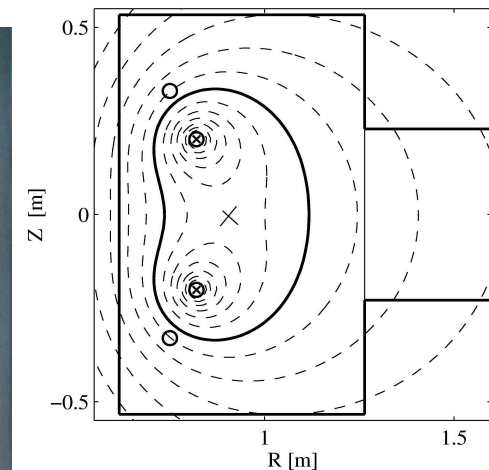
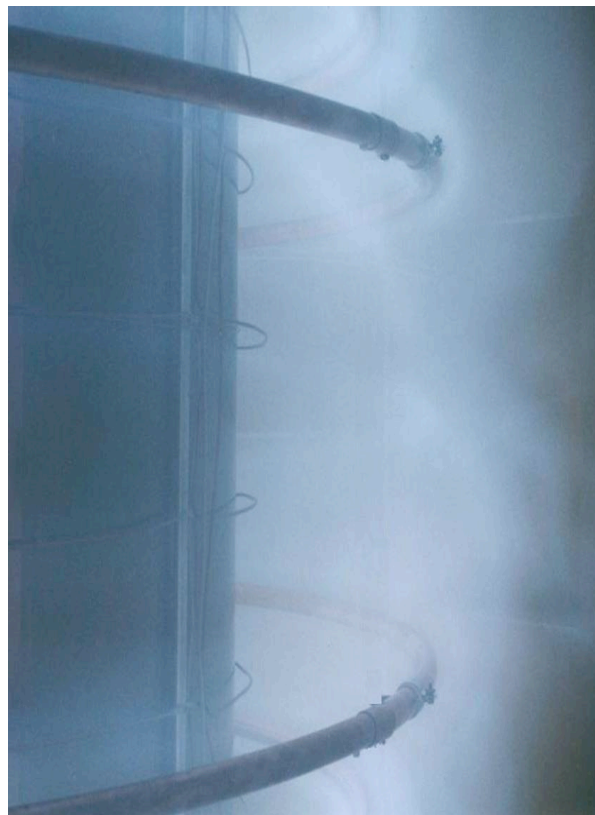


New VTF Configuration for FY 2005-2007

(VTF is partially funded as member of the new OFES funded Center for Multi-Scale Plasma Dynamics led by UMD and UCLA)

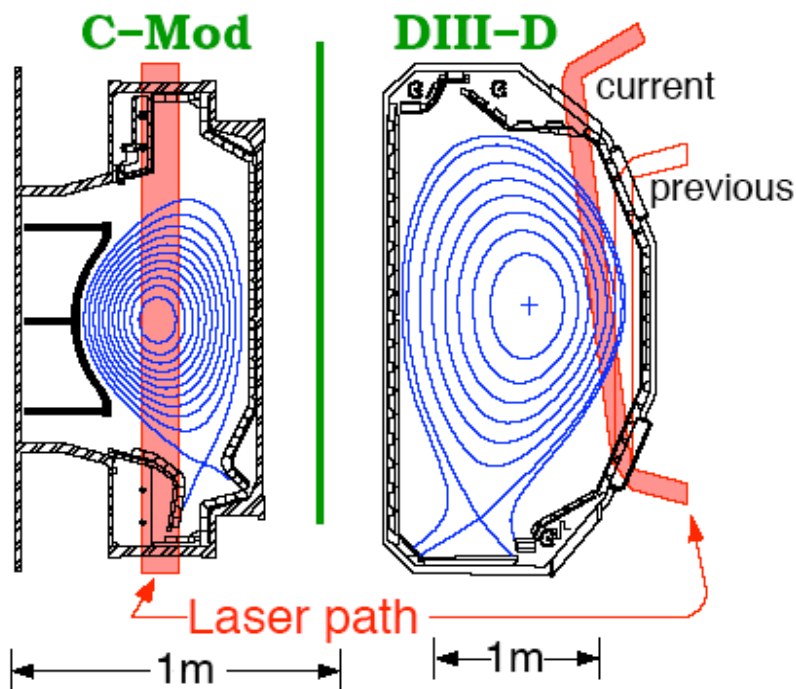
New closed magnetic geometry implemented in VTF for the study of collisionless reconnection in a configuration relevant to the ongoing theoretical study: Geospace Environment Reconnection (GEM) challenge as well as reconnection in fusion plasmas

As illustrated on the RHS diagram, a new reconnection drive scenario has been developed where reconnection is driven by transferring the coil current from the center loops to the outer loops.



PCI beam geometry is being modified on DIII-D to look for modes in the plasma core; stage 1 shown in figure; stage 2 to follow by moving the bottom beam location inward; in C-Mod the beam remains as shown

PCI geometry on DIII-D and C-Mod



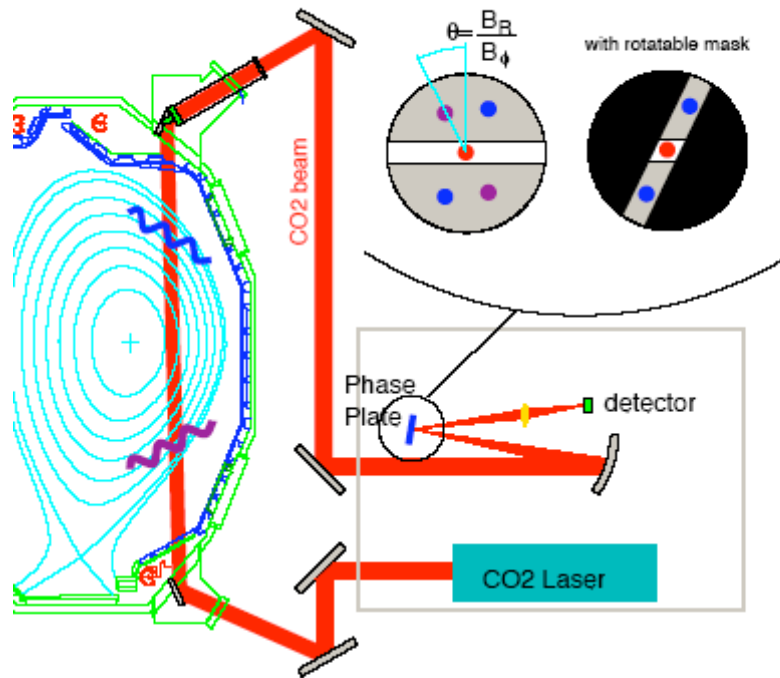
DIII-D

- Beam formerly near LCFS ($k_\theta \sim 0$)
- Past focus: edge turbulence, ELMs, H-modes
- Beam now in core plasma: access to study electron transport, internal transport barriers, different k in edge

Alcator C-Mod

- Beam in plasma center
- Past focus: ICRF, coherent modes
- New focus: ICRF-MC, ETG/TEM turbulence

Localization along the laser beam achieved by a rotating masking plate; Works only for short wavelength modes ($k_{\perp} \geq 10 \text{ cm}^{-1}$), For Example ETG and TEM modes



- Modes have $k_{\parallel} \ll k_{\perp}$
- Scattering is \perp to $B_R(z) + B_{\phi}$ (\sim radial)
- Modes scattered from different z focused at different pitch angles on phase plate
- Phase plate mask selects pitch angle

The "Tore Supra Technique"^a

^aA. Truc et al, "ALTAIR: An infrared laser scattering diagnostic on the TORE SUPRA tokamak", RSI **63** (1992), p. 3716.

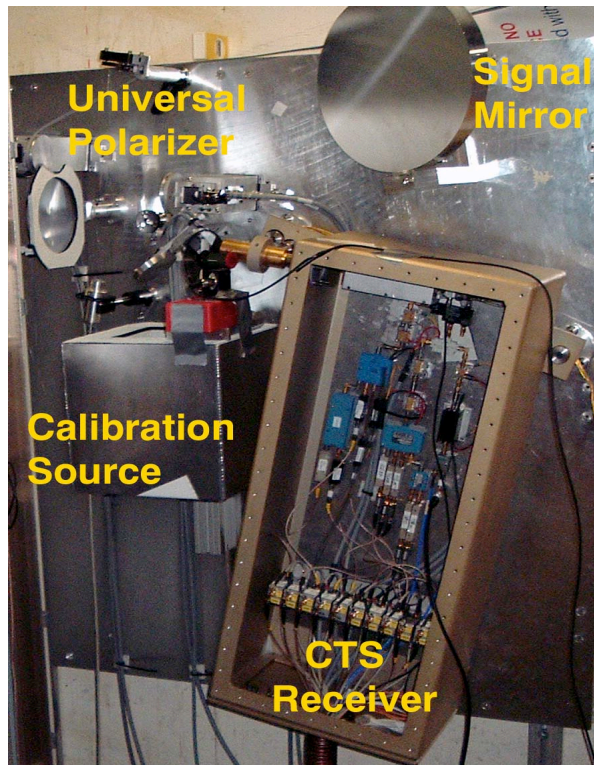


TEXTOR Fast Ion Coll. Thomson Scattering

P. Woskov, Int. Collaboration with H. Binslev, Riso, Denmark

Receiver
 v_{\perp} or v_{\parallel}

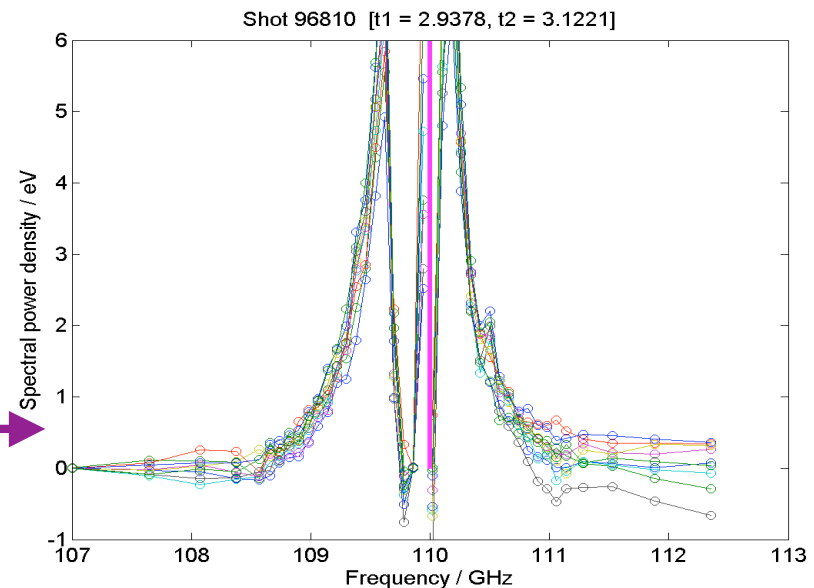
Probe:
110 GHz
100 kW
200 ms



- Generic fast ion physics
Sawteeth redistribution
- ICRH physics
Fusion α absorption ?
- Develop fast ion CTS for
fusion plasmas

Recommisioned Feb. 2005:

- Initial results with NBI
- Testing of beam overlap and
universal polarizer

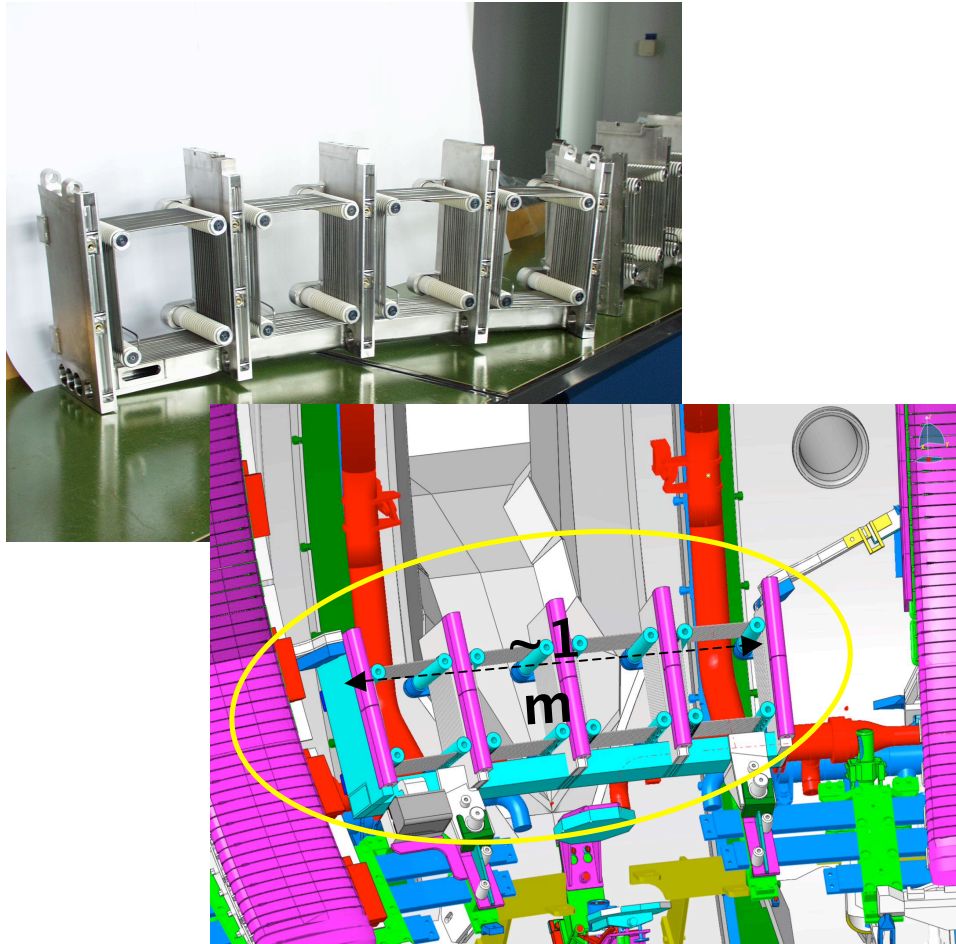




Fast Particle-Wave Interaction and Alfvén Eigenmodes in JET

- **Scope** • one post-doc on site at JET full-time to analyze TAE experiments
 - part-time engineering support from MIT for diagnostic development
- **Results** • low n simultaneous TAE and EAE damping rate measurements
 - n=1 damping rate drops as q_0 decreases → low shear provides strong damping
 - n=0 chirping modes with inboard ICRF may be driven by phase space gradient
 - new data acquisition system provided by MIT for fast fluctuation measurements
 - new moderate toroidal mode number TAE antennas designed with MIT support
- **Plans** • provide continued physics/engineering support with the new antennas
 - to excite ITER relevant moderate toroidal mode numbers
 - to determine their damping rates versus shaping and dimensionless parameters
- **Submit renewal proposal for 3 years starting Dec. 2005 at \$130K/year**

New Active TAE Antennas for JET



- Designed with substantial engineering support from MIT
- Will excite higher toroidal mode number $n \sim 10$ TAEs similar to those expected in ITER
- To be installed in April 2005



PSFC Theory Group (Peter J. Catto, Head)

- PSFC theorists participating in 3 new SCiDAC proposals

Funding of one or more of these should help retain key staff and students and provide support for ongoing experiments (C-Mod, LDX, VTF) and ITER

- Theory Grant Proposal is being prepared for submission for renewal
- Spectacular new results with the new 48 parallel processor cluster

New request for FY 06/07:

- Propose to upgrade cluster to 128 processors at a cost of \$150K

Request \$75K new money from OFES, and the PSFC/C-Mod combination will match these funds (\$75K); in addition, MIT pledged \$50K to upgrade the facilities by increasing the airconditioning capacity (new unit and installation)

- In addition, request \$70K for new student RA

The cluster upgrade would enable us to:

- Non-linear simulations with GS2 and GYRO
- Practical turnaround time for code development and testing
- Converged LH runs for planned C-Mod experiments
- Combining TORIC AND TOPICA ICRF codes (full wave and antenna model)
- Coupled TORIC and CQL3D runs

“Synthetic” PCI Diagnostic Based on TORIC Code Predicts “Footprint” of Slow Kinetic ICRF Waves in Remarkable Agreement with Experiment

RF wave driven density fluctuations are proportional to the divergence of the perturbed velocity.

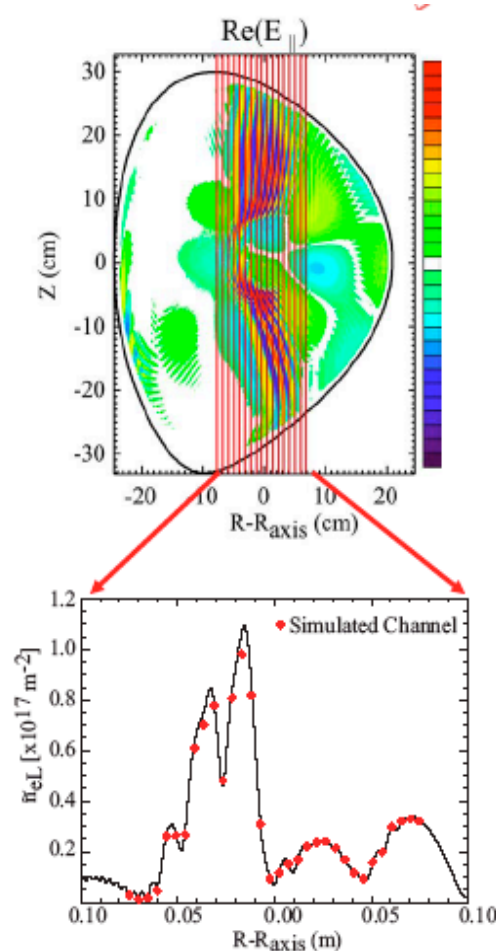
$$\frac{\tilde{n}_e}{n_{e0}} = \frac{-i}{\omega} \nabla \cdot \tilde{\mathbf{v}}_e$$

$$\tilde{\mathbf{v}}_e \equiv -i \frac{\Omega_e}{\omega} \frac{E_\zeta}{B_0} \hat{\zeta} + \frac{E_\eta}{B_0} \hat{\psi} - \frac{E_\psi}{B_0} \hat{\eta}$$

$$\frac{\Omega_e}{\omega} \gg 1 \text{ and } E_\eta \sim E_\psi$$

- Where perturbed velocity and E-field is written in local Stix coordinates.
- Simple rule for predicting dominant contribution is difficult because it is a function of both wavelength and field strength.

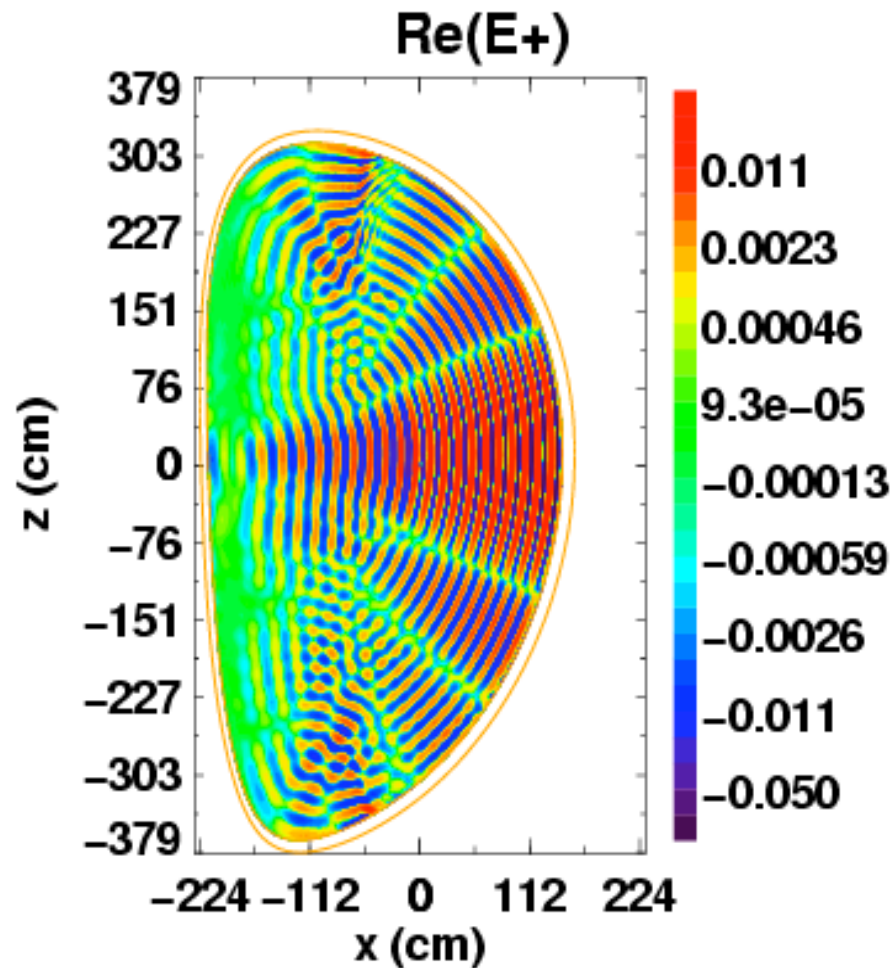
Line integrate calculated 2-D fluctuations and use same analysis as used for experiment.





2nd Harmonic Tritium Heating in ITER (Aries AT 2001 Reference Case used in TORIC)

$T_e=23.5$ keV; $T_i=19.5$ keV; $T(^3\text{He})=0.4$ MeV; $T(\alpha)=1.6$ MeV



❖ MPP version of TORIC can solve for absorption for a single toroidal mode in ITER on 40 processors in 40 minutes

❖ Plan to couple TORIC to CQL3D and Sigma-D to study effects of alphas and fast ions in ITER

❖ Power deposition:

Electrons: 45%;

^3He : 46%;

T: 2%

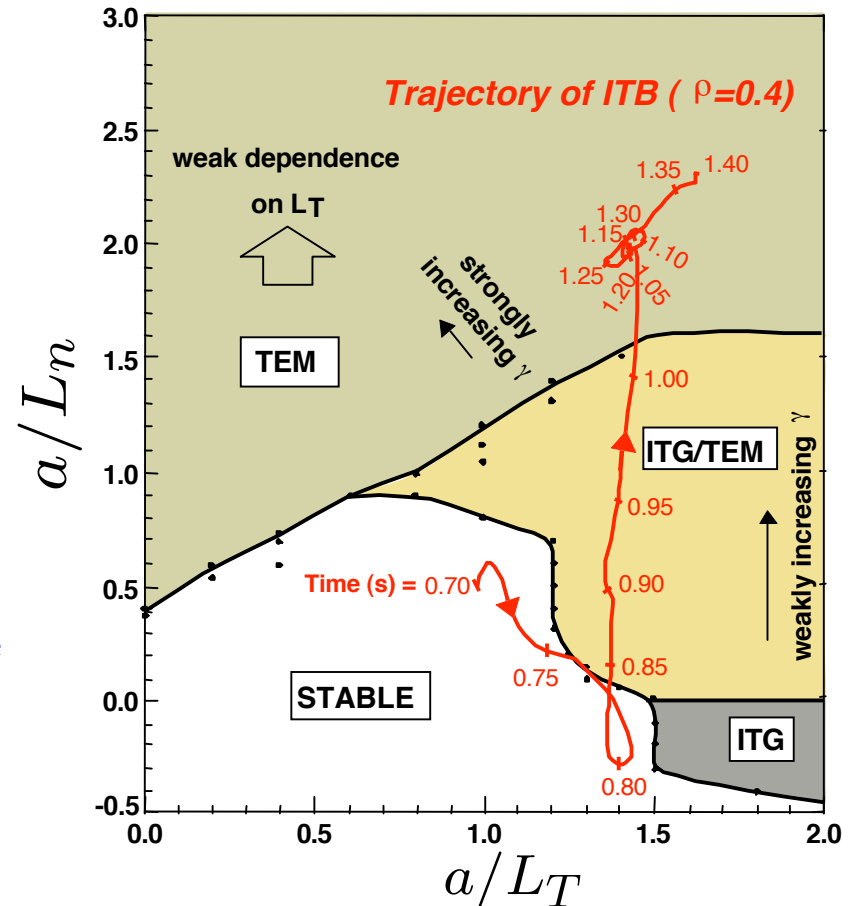
Alpha: 6%

Gyrokinetic Stability Analysis of C-Mod ITB

(Darin Ernst)

Gyrokinetic stability analysis of temporal evolution of ITB reveals coherent physics picture of formation and control.

- Initially near ITG marginal stability, allowing Ware pinch to peak density
- When critical density gradient exceeded, TEM unstable: large particle diffusion
- TEM particle transport balances Ware pinch; trajectory stagnates

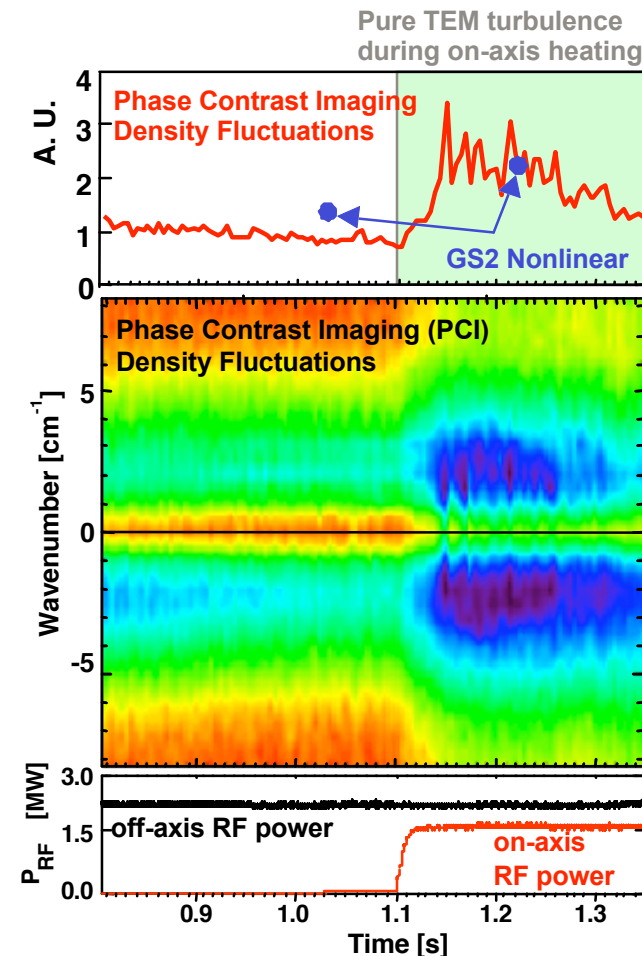


GS2 Simulations & Phase Contrast Imaging Reveal Trapped Electron Mode Turbulence in C-Mod ITB

(Darin Ernst-theory, Nils Basse et al, -expt)

Gyrokinetic turbulence simulations of ITB using GS2 elucidate physics, and agree with experiments within measurement uncertainty.

- Trapped electron modes (TEM) are destabilized as the density gradient steepens
- New TEM nonlinear upshift: The nonlinear critical a/L_n exceeds the linear value due to turbulence self-quenching by zonal flows
- The turbulent outflow balances the Ware pinch, leading to steady state in the ITB
- The TEM turbulent diffusivity exhibits a strong unfavorable temperature dependence, hence heating with strong on-axis ICRH (in addition to off-axis ICRH) controls the ITB density peaking

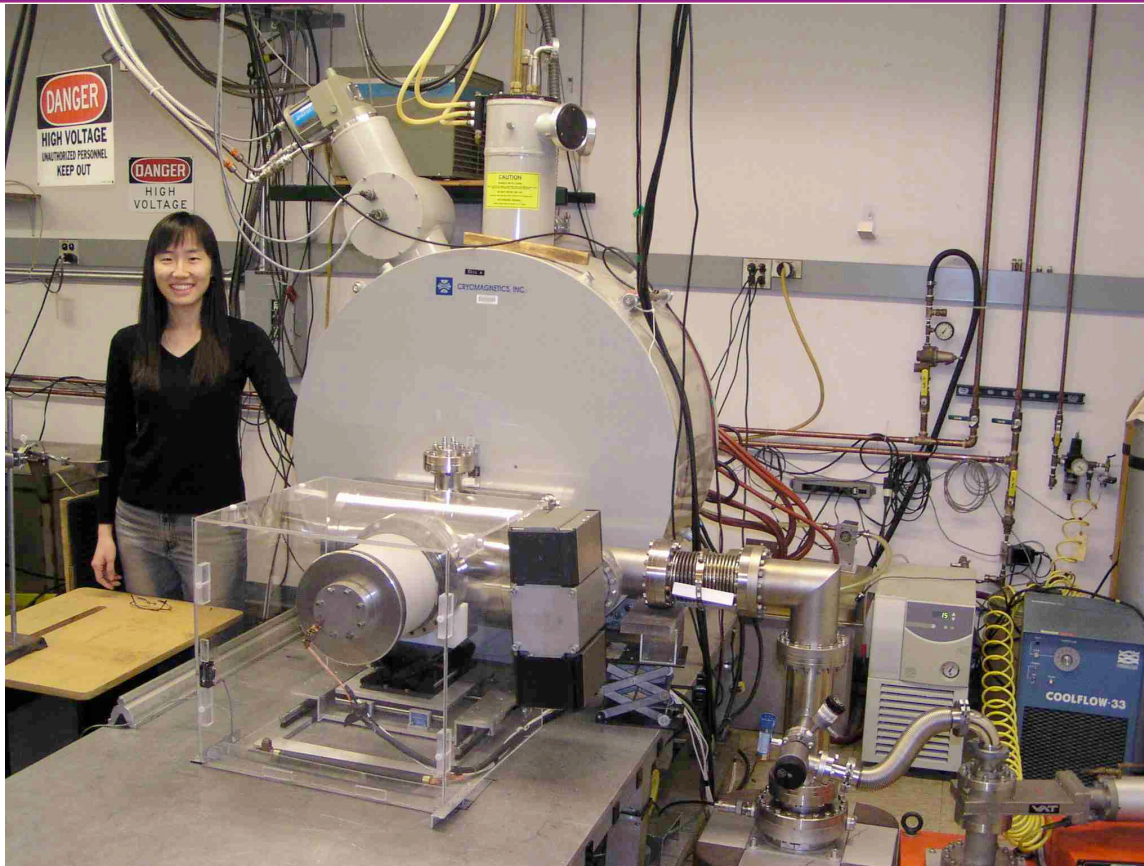


D. R. Ernst et al., IAEA 2005



WAVES AND BEAMS DIVISION

ECH Program Accomplishments in FY05



Physics Grad Student Ms. E. Choi with 1.6 MW, 110 GHz internal mode converter gyrotron experiment at MIT

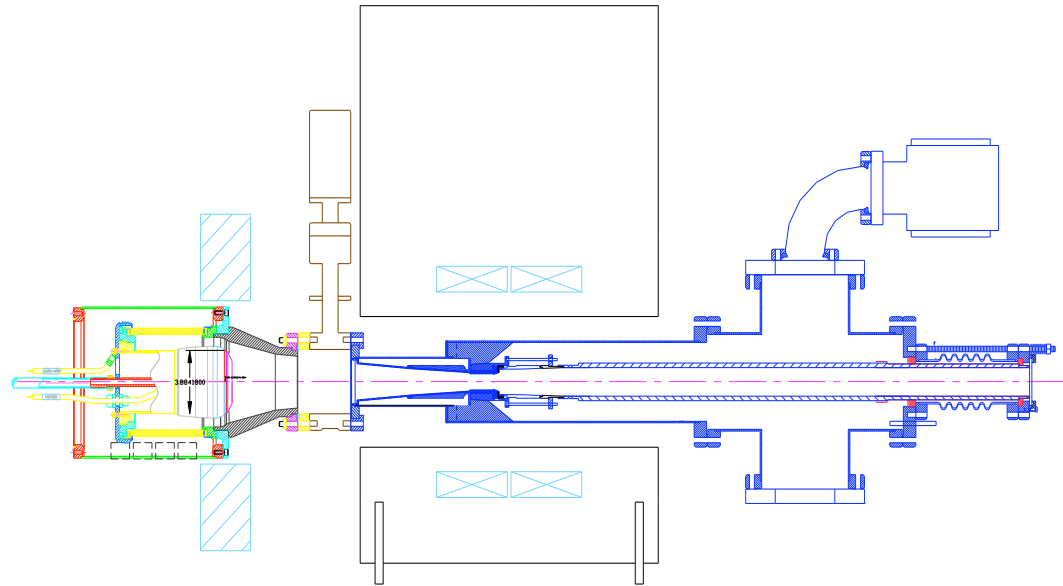
- **Demonstration of 1.6 MW, 110 GHz at 42% efficiency in three microsecond pulse operation at MIT.**
- **Results in good agreement with Univ. MD code, MAGY.**
- **Results demonstrate that the full power of > 1.5 MW can be achieved.**

WAVES AND BEAMS DIVISION

ECH Program Plans FY06/FY07

- **ITER Research:**

- Design of ITER 1 MW, 120 GHz Gyrotron .
- Improved Modeling Tools for gyrotron design.
- Participate in engineering design of ITER system, including transmission line.



- **VLT Program Research:**

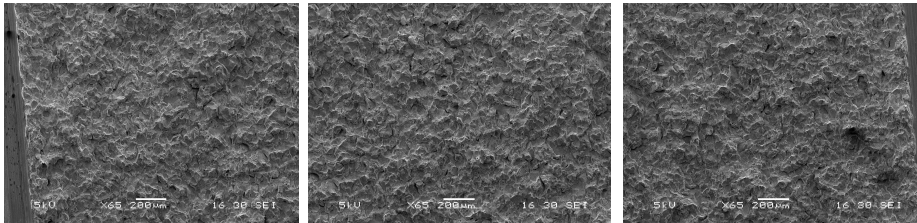
- Design of Next Step Gyrotron for basic (student) research at MIT.
- Design and build 1.5 to 2 MW, tunable 120 GHz gyrotron to advance both basic research and ITER goals.
 - Collaborate with Univ. MD, Univ. WI, CPI and GA.



Magnet Technology FY05 Technical Highlights

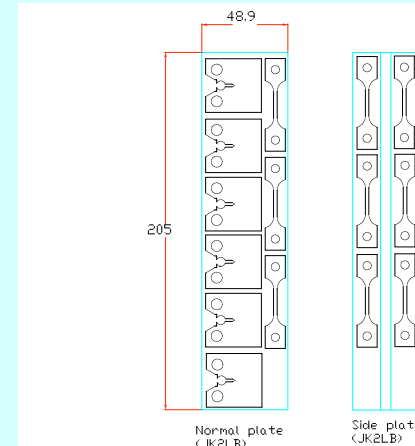
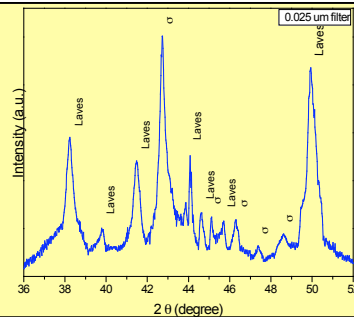
- Magnet program focused on preparations for ITER - Development of project plan, cost and schedule for supply of part or all of Central Solenoid.
- Major fraction of VLT base funding supports ITER effort:
 - Task Agreements completed in 3 areas:
 - **Stress Analysis of the Helium Inlet Regions (ITA 11-20)**
 - **Conductor Performance and Design Criteria (ITA 11-22)**
 - **CS Jacket Weld Defect Assessment (ITA 11-23)**
 - Nb₃Sn superconducting wire industrial qualification contracts placed with 3 US vendors
 - Full-size development begun
 - Jacket welding and characterization
 - Cabling
 - Full-size test samples
 - Lap Joints
 - **Phil Michael spends half-time in Naka working with ITER Team**
- Three new strand/cable experiments in process. Measurements/analysis expected this summer.

Magnet Technology FY05 Technical Highlights



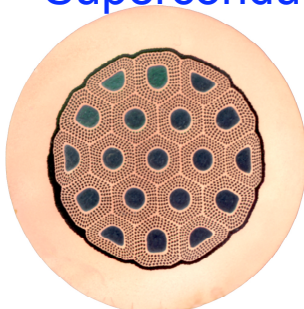
Fracture surface of JK2LB with brittle behavior

The X-ray diffraction results indicating the presence of sigma and Laves phase in JK2LB sample. Indicates not suitable for use in ITER CS.

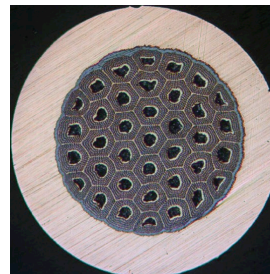


Test samples used for mechanical characterization of jacket materials

Superconducting wires under development for ITER CS (diameter ~0.8mm)



OXFORD
INSTRUMENTS



Outkumpu Advanced
Superconductors



SUPERCONDUCTING SYSTEMS, INC.



FUSION TECHNOLOGY PLANS FY 06, 07

- Superconducting magnet R&D spending and plans depend on actual ITER funding for FY 06, 07; see ITER/VLT budget scenarios
- In the PSFC budget table we presented magnet R&D budgets based on only minimal (\$16M) increase for ITER funding for FY 06; no projection for FY 07 was made; however, if ITER were to proceed to construction, magnet funding alone would have to increase by as much as \$22M



SUMMARY of MIT REQUESTS for FY 06/07

- **C-Mod: restore funding in FY 06, to increase run time at least up to 14 weeks (\$500K), with further increases in FY 07**
- **LDX : increase funding by \$155K to increase run-time and student RA**
- **VTF: Addition of one technician needed at \$100K**
- **Theory: Need \$75K matching funds to upgrade computer cluster and additional \$70K to add one more student RA**
- **ECRH : Maintain the VLT base to support graduate student RA work and provide funding for ITER work as included in the VLT/ITER request**
- **Magnets: Maintain the VLT base and provide for ITER \$3.1M in FY06 and at least \$17.2 M in FY07 (assumes no ITER construction startup in FY 06, or higher funding level necessary)**